SYSTEM AND METHOD FOR CURRENT SENSING USING ANTI-DIFFERENTIAL, ERROR CORRECTING CURRENT SENSING

DESCRIPTION

CROSS-REFERENCE TO RELATED APPLICATION

[Para 1] This application claims the benefit of prior U.S. Provisional Application Serial No. 60/507,896 filed October 1, 2003 and entitled INTEGRATED, COMMUNICATING, NON-CONTACT CURRENT SENSOR AND ARC FAULT DETECTOR FOR BUS, CABLE AND FEED THROUGH INSTALLATIONS.

BACKGROUND OF THE INVENTION

[Para 2] The present invention relates generally to current measuring and monitoring, more particularly, to a system and method for measuring current by sensing magnetic flux associated with current flow through a conductor. A dual Hall sensor configuration is utilized to sense magnetic flux and provide feedback to a processing component. The processing component is arranged to generate an anti-differential output from the feedback received to remove feedback attributable to magnetic fields induced externally from the conductor.

[Para 3] Measuring and monitoring of current flow through a conductor is an important analysis that is performed in a wide variety of applications and circumstances. Current sensing designs often fall into one of two categories: contact topologies and non-contact topologies.

[Para 4] Contact sensors are common in many circumstances but include many inherent limitations. For example, while shunt-type sensors are readily applicable to direct current (DC) applications, shunt-type sensors are not suited to alternating current (AC) applications due to errors caused by induced loop voltages. On the other hand, while current transformers (CT) are suited for AC applications, such are inapplicable to DC applications due to the fundamental nature of transformers.

[Para 5] In any case, these contact-based sensor systems are typically large and may be difficult to employ, especially in areas where tight size constraints are necessary. Specifically, in order to deploy a contact-based sensor, such as a resistive shunt, it is necessary to remove the conductor from service. Additionally, shunt based sensors require lugs to form an electrical connection and a mounting means to secure the device in position. Similarly, CT-based sensors necessarily require adequate accommodations for a transformer.

[Para 6] Non-contact current sensing designs are often preferred in many applications because they reduce common mode noise typically experienced with direct contact designs, such as shunts. Non-contact designs also reduce heat buildups often associated with resistive shunts and the need to use burdened current transformers. Additionally, non-contact designs provide scalable outputs that are desirable for use with digital controllers.

[Para 7] A variety of designs and approaches have been developed for non-contact current monitoring systems. One common and desirable form of non-contact sensing and monitoring of current flow includes indirectly determining current flow through a conductor by detecting a magnetic field or flux induced as a result of the current flow through the conductor.

[Para 8] For example, metal core based systems are often used to measure the current flow through a conductor by detecting the magnetic flux induced by the current flow. The metal core is utilized to magnify the magnetic flux concentration and, thereby, provide increased accuracy in detecting the magnetic flux and the extrapolated current readings. Various topologies including "open-loop," "closed-loop," "flux gate," and "dithering" designs may be utilized, although all include limitations.

[Para 9] Open-loop sensors use the magnetic properties of the metal core material to magnify the magnetic flux induced by the current flow through the conductor. However, to extrapolate the current measurements from the detected magnetic flux, these sensors rely on the "near linear" operational range of the metal core. A ferromagnetic core that enters a "saturation" operational range can distort the reported current compared to the actual current profile. Specifically, as saturation is reached, a current level that changes with time produces a time changing magnetizing force that produces a time changing magnetic flux density within the core. That is, as the core material approaches magnetic saturation, the "magnetic gain" declines and approaches the "magnetic gain" of air. As such, the magnetic field within the metal core is distorted in proportion to the difference in permeability at various points along a hysteresis loop of the metal core. Therefore, should the operating conditions lead to the saturation of the metal core, inaccurate current measurements may be gathered. Accordingly, sensing ranges of metal core sensors are typically hard-limited to the "near-linear" operational range.

[Para 10] Additionally, sensors relying on metal cores can experience hysteresis in the metal core that may produce a zero current offset error. Specifically, when at low or zero current levels, the metal core may act as a weak permanent magnet and report a persistent flux though little or no current is actually present. As such, zero offsets are particularly troublesome when monitoring DC power systems. As all permeable ferromagnetic materials exhibit some level of hysteresis, which produces an error at zero current,

metal core sensors are susceptible to erroneous current measurements at low or no current levels. Furthermore, increased inductance can produce phase shifts between the actual current profile and the reported current profile.

[Para 11] Furthermore, while electronic-based sensors are typically limited by the voltage rails used in the sensor output stages, current sensors employing metal cores have an additional limitation imposed by the saturation point of the material. For example, a sensor with a scale factor of 1 volt per amp with a 5 volt rail will be limited to 5 amps regardless of the range of the detector. In metal core based sensors it is well known that the dynamic range is typically limited to 10:1. Therefore, it is known that metal core current sensors include range, accuracy, and repeatability limits in proportion to the propensity for hysteresis, saturation, and non-linearity of the material used in the core.

[Para 12] "Closed-loop" sensors, flux gate approaches, and dithering approaches utilize a combination of electronic circuits and bucking coils to compensate for these material related errors and/or average-out errors. However, these systems merely diminish the effects of the errors, and do not entirely eliminate the potential for errors and incorrect current readings.

[Para 13] Accordingly, in order to eliminate the potential for inaccurate current measurements due to metal core saturation, hysteresis, or eddy currents, air-core sensors may be used to measure and monitor current. However, while the removal of the metal core eliminates the potential for inaccurate current measurements due to metal core saturation, hysteresis, or eddy currents, the air core does not have the magnetic flux magnifying or concentrating effect of metal cores. Therefore, air-core current sensors are readily susceptible to influence by external magnetic fields and may provide inaccurate current measurements. As such, air-core sensors are typically unsuitable for applications where multiple high external magnetic fields are present. As an overwhelming percentage of current sensors are required to be

deployed in areas where numerous conductors and corresponding magnetic fields are in close proximity, air-core sensors are often undesirable.

[Para 14] It would therefore be desirable to design a system and method for non-contact current sensing that does not rely on ferromagnetic materials and is not susceptible to magnetic fields induced externally from the monitored conductor. That is, it would be desirable to have a system and method for non-contact current sensing that does not include the inherent limitations of metal-core based current sensors while providing accurate current feedback in the presence of external magnetic fields. Furthermore, it would be desirable to have a system and method for concentrating magnetic flux associated with a particular conduction to increase monitoring accuracy.

BRIEF DESCRIPTION OF THE INVENTION

[Para 15] The present invention is directed to a system and method that overcomes the aforementioned drawbacks. Specifically, an anti-differential, error correcting, sensor topology is utilized that eliminates the need for ferromagnetic concentrators. As such, the sensor eliminates the limitations associated with metal-core based current sensors and is capable of providing accurate current monitoring in the presence of external magnetic fields.

[Para 16] In accordance with one aspect of the invention, a current monitoring system is disclosed that includes a conductive path configured to receive a current therethrough, a first current sensor positioned on a first side of the conductive path and configured to monitor a first directional magnetic field induced by the current, and a second current sensor positioned on a second side of the conductive path, substantially opposite the first current sensor, and configured to monitor a second directional magnetic field induced by the current that is substantially opposite in direction to the first directional magnetic field. A processing component is configured to receive feedback

from the first current sensor and the second current sensor and generate an anti-differential output from the feedback.

[Para 17] According to another aspect of the invention, a current sensor is disclosed that includes a first Hall effect sensor positioned proximate to a conductor and configured to provide a first feedback indicative of a current flow through the conductor and a second Hall effect sensor positioned proximate to the conductor and configured to provide a second feedback indicative of the current flow through the conductor. A processing device is configured to generate a summed difference of the first feedback and the second feedback to reduce feedback corresponding to magnetic fields induced externally from the conductor.

[Para 18] In accordance with another aspect, the invention includes a method of determining current flow through an electrical path. The method includes generating a first feedback represented by a first vector having a first direction and a first magnitude upon detecting a first direction of magnetic flux induced by a current flow through an electrical path and a second vector having the first direction and a second magnitude upon detecting a second direction of magnetic flux induced externally from the electrical path. The method also includes generating a second feedback represented by a third vector having the first direction and the first magnitude upon detecting a third direction of magnetic flux induced by the current flow through the electrical path and a fourth vector having a second direction and the second magnitude upon detecting the second direction of magnetic flux induced externally from the electrical path. The method then includes summing the first feedback and the second feedback to create an anti-differential sum thereby substantially canceling the effects of the first feedback and the second feedback represented by the second vector and the fourth vector.

[Para 19] In accordance with yet another aspect of the invention, an anti-differential current sensing system is disclosed that includes an electrically conductive path. A first Hall effect sensor is disposed proximate to a first side of the electrically conductive path and configured to generate a first measure of a current flow through the electrically conductive path by monitoring magnetic fields and a second Hall effect sensor is disposed proximate to a second side of the electrically conductive path, substantially opposite the first side of the electrically conductive path, and configured to generate a second measure of the current flow through the electrically conductive path by monitoring magnetic fields. A processing device is configured to receive the first measure of the current flow and the second measure of the current flow and generate an output from the first measure of the current flow and the second measure of the current flow substantially free of errors due to magnetic fields generated externally from the conductive path.

[Para 20] According to another aspect of the invention, a current sensor system is disclosed that includes means for carrying current and means for generating a first feedback upon detecting magnetic flux in a first direction induced from the means for carrying current. The current sensor system also includes means for generating a second feedback upon detecting magnetic flux in a second direction induced from the means for carrying current, wherein the first direction is substantially opposite the direction and means for generating an anti-differential sum from the first feedback and the second feedback to reduce feedback generated upon detecting stray magnetic flux.

[Para 21] Various other features and advantages of the present invention will be made apparent from the following detailed description and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[Para 22] The drawings illustrate one preferred embodiment presently contemplated for carrying out the invention.

[Para 23] In the drawings:

[Para 24] Fig. 1 is a perspective diagram of an anti-differential current sensor configuration in accordance with the present invention.

[Para 25] Fig. 2 is a schematic of one embodiment of the anti-differential current sensor configuration of Fig. 1 in accordance with the present invention.

[Para 26] Fig. 3 is a schematic of another embodiment of the anti-differential current sensor configuration of Fig. 1 in accordance with the present invention.

[Para 27] Fig. 4 is a graph illustrating the relationship between the influence of external magnetic fields and conductor position in accordance with the present invention.

[Para 28] Fig. 5 is an illustration of the influence of magnetic field strength upon parallel conductors at a first distance.

[Para 29] Fig. 6 is an illustration of the influence of magnetic field strength upon parallel conductors at a second distance.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[Para 30] The present invention is related to a system and method for non-contact based, anti-differential, error-correcting current sensing. A plurality of magnetic flux sensors is arranged about a conductor and provides feedback to a processing component or device configured to generate an output with reduced feedback induced by magnetic fields external to the conductor. The plurality of magnetic flux sensors may be disposed in geometrically designed recesses configured to amplify the magnetic flux received by the plurality of magnetic flux sensors. The system may be disposed in a variety of configurations designed for optimal disposition of the plurality of magnetic flux sensors about a given conductor type. Some examples of possible configurations include etched spiral path topologies for low current and

printed circuit board current sensing, dual-spiral and spiral-helix topologies for contact based current sensing, and wire and bus bar mount topologies for wire and bus bar conductors. Furthermore, the system may be integrated with additional systems that utilize current sensing as well as communication interfaces.

[Para 31] Referring to Fig. 1, a perspective view is shown of an anti-differential current sensor configuration 10 arranged about a conductor 12 in accordance with the present invention. The conductor 12 is illustrated as a round wire for exemplary purposes only but, as will be described, may include any form of current conductor including bus bars, integrated circuits, printed circuit boards, circuit breakers, and the like. The conductor includes a current flow therethrough, as illustrated by an arrow 14 and labeled "I." As is well known, the current flow 14 through the conductor 12 induces a magnetic field, as illustrated by arrows 16, labeled "B_1." Two magnetic flux sensors H_1, H_2, preferably Hall effect sensors, are disposed on substantially opposite sides of the conductor 12. The positioning of the Hall effect sensors H_1, H_2 on substantially opposite sides of the conductor 12 aids in reducing the effects of externally induced magnetic fields, labeled "B_2" and illustrated by arrows 17, that can otherwise cause inaccurate readings of the current 14 through the conductor 12. That is, the two current sensors H_1, H_2 are used in a configuration that reports the current inside the conductor 12 to a processing component 18 that is configured to calculate a sum or summed difference of the feedback from the two current sensors H_1, H_2 to generate an anti-differential output having reduced influences from externally induced magnetic fields B_2 17. Specifically, the anti-differential current sensor configuration 10 provides an anti-differential output 19 that is a highly accurate indication of the current flow 14 through the conductor 12 and is substantially free of influence from externally induced magnetic fields B_2 17.

[Para 32] The anti-differential current sensor configuration 10 may include various architectures or configurations of the current sensors H_1, H_2

and processing component 18. Referring now to Fig. 2, a first configuration of the anti-differential current sensor configuration 10a is shown. The conductor 12 is again shown with opposing Hall effect sensors H_1, H_2 disposed about a periphery of the conductor 12. Figure 2 illustrates the conductor 12 in the form of a wire. However, it is contemplated that the conductor may be of various forms. Therefore, Fig. 2 shows the conductor 12 as a wire conductor while Fig. 3 shows a conductor 12a in the form of a bus bar. Additionally, it is contemplated that the Hall effect sensors H_1, H_2 may not only be disposed about the periphery of the conductor 12 but may be disposed within flux concentrating recesses within the conductor 12 to improve the magnetic flux detected by the Hall effect sensors H_1, H_2.

[Para 33] The current flow 14 through the conductor 12 is again represented as "I" and the associated magnetic field, which circles the conductor, is represented as "B_1," 16. According to the first configuration of the anti-differential current sensor 10a, the Hall effect sensors H_1, H_2 are not only disposed on opposite sides of the conductor 12 but are also configured to provide feedback of positively designated current flow upon detecting oppositely directed magnetic flux. That is, Hall effect sensor H_1 provides feedback indicating that a positive current value of magnitude "I" has been determined upon detecting a directional magnetic flux in a first direction 20. Therefore, the feedback generated by Hall effect sensor H_1 upon detecting directional magnetic flux B_1 16 in the first direction 20 is represented as "$+I_{B1}$," 21.

[Para 34] On the other hand, according to the first configuration of the anti-differential current sensor 10a, Hall effect sensor H_2 is configured to provide feedback indicating that a positively designated current flow has been determined upon detecting a directional magnetic flux in a second direction 22. Therefore, the feedback generated by Hall effect sensor H_2 upon detecting directional magnetic flux B_1 16 in the second direction 22 is also represented as "$+I_{B1}$," 24. Accordingly, even though the directions 20, 22 of the magnetic

flux B_1 16 are substantially opposite in direction when detected by Hall effect sensor H_1 as opposed to Hall effect sensor H_2, both Hall effect sensors H_1, H_2 provide positive feedback "$^+I_{B1}$," 21, 24.

[Para 35] Following this convention, upon detecting a stray or foreign magnetic field B_2 17 that is induced or generated externally to the conductor 12 and generally impinges upon each Hall effect sensor H_1, H_2 substantially equally, the Hall effect sensors H_1, H_2 provide substantially equal and opposite feedback. Specifically, unlike the magnetic field B_1 16 induced by the current flow 14 through the conductor 12, which uniformly encircles the conductor 12, the externally induced magnetic field B_2 17 is generally directionally uniform with respect to impinging upon the Hall effect sensors H_1, H_2. Accordingly, due to the directional configuration of the Hall effect sensors H_1, H_2, Hall effect sensor H_1 will provide feedback indicating a positive current flow upon detecting the magnetic field B_2, while Hall effect sensor H_2 will provide feedback indicating a negative current flow upon detecting the magnetic field B_2 17. That is, Hall effect sensor H_1 will provide positive feedback "$^+I_{B2}$," 26 while Hall effect sensor H_2 will provide negative feedback "$^-I_{B2}$," 28.

[Para 36] All feedback, $^+I_{B1}$, $^+I_{B2}$, $^+I_{B1}$, and $^-I_{B2}$, is then passed to a processing component 18a. According to the first configuration of the anti-differential current sensor 10a, the processing component 18a is a summing amplifier, such as a summing operational amplifier (op amp), and is configured to provide an algebraically summed anti-differential output. However, while the processing component 18a is illustrated as a summing op amp, it is contemplated that a wide variety of processing components may be utilized. Specifically, any processing component, whether analog or digital, that is capable of generating an anti-differential sum of feedback received may be utilized within the anti-differential current sensor configuration 10a. Therefore, the term "processing component" as utilized herein is defined to include any analog, digital, or discrete components that may be configured to generate an algebraic sum of its inputs.

[Para 37] Therefore, the processing component 18a receives all feedback from the Hall sensors H_1, H_2 and provides a sum of $^{+}I_{B1} + {}^{+}I_{B1} + {}^{+}I_{B2} + {}^{-}I_{B2}$. As such, the feedback generated in response to the externally induced magnetic flux B_2 17 ($^{+}I_{B2}$, $^{-}I_{B2}$) cancels and the anti-differential output 30 of the processing component 18a is generally twice the current flow 14 through the conductor 12, as determined from the magnetic field B_1. Therefore, regardless of the strength, direction, or concentration of extraneous magnetic fields B_2 17, the output 30 of the processing component 18a is $^{+}2I_{B1}$. The first configuration of the anti-differential current sensor configuration 10a thereby yields accurate current measurements by reducing, if not essentially removing, feedback associated with stray magnetic fields B_2 17 induced or generated externally to the conductor 12 from which current feedback is desired.

[Para 38] Referring now to Fig. 3, a second configuration of the anti-differential current sensor 10b is shown. For exemplary purposes, Fig. 3 illustrates a conductor 12a, this time in the form of a bus bar. Again, it is contemplated that the Hall effect sensors H_1, H_2 may not only be disposed about the periphery of the conductor 12a but may be disposed within flux concentrating recesses within the conductor 12a to improve the magnetic flux detected by the Hall effect sensors H_1, H_2.

[Para 39] As will be described in detail below, the second configuration of the anti-differential current sensor 10b differs from the first configuration of the anti-differential current sensor 10b shown in Fig. 2 by the architecture or configuration of the Hall effect sensors H_1, H_2 and the configuration of the processing component 18b. Specifically, due to the configuration of the Hall effect sensors H_1, H_2 about the conductor 12a, the processing component 18b is configured as a differential or "differencing" amplifier.

[Para 40] In accordance with one embodiment, the differential amplifier is a differential op amp, configured to calculate an algebraically summed difference of the feedback received to generate an anti-differential output. However, while the processing component 18b is illustrated as a differential op amp, it is equally contemplated that a wide variety of processing components may be utilized. Specifically, any processing component, whether analog or digital, that is capable of calculating a summed difference of feedback received to generate the desired anti-differential output may be utilized within the anti-differential current sensor configuration 10b. Therefore, the term "processing component" as utilized herein is again defined to include any analog, digital, or discrete components that may be configured to generate an algebraic sum of feedback received.

[Para 41] According to the second configuration of the anti-differential current sensor 10b, the Hall effect sensors H_1, H_2 are disposed on opposite sides of the conductor 12a and are configured to provide equal and oppositely designated feedback of the current flow 14 through the conductor 12a upon detecting oppositely directed magnetic flux 20, 22. That is, Hall effect sensor H_1 provides feedback indicating that a positive current value of magnitude "I" has been determined upon detecting a directional magnetic flux in a first direction 20. Therefore, the feedback generated by Hall effect sensor H_1 upon detecting directional magnetic flux B_1 16 in the first direction 20 is represented as "$+I_{B1}$," 21.

[Para 42] On the other hand, according to the second configuration of the anti-differential current sensor 10b, Hall effect sensor H_2 is configured to provide feedback indicating that a negatively designated current flow has been determined upon detecting a directional magnetic flux in a second direction 22. Therefore, the feedback generated by Hall effect sensor H_2 upon detecting directional magnetic flux B_1 16 in the second direction 22 is represented as "$-I_{B1}$," 24a. Accordingly, since the directions 20, 22 of the magnetic flux B_1 16 are substantially opposite when detected by Hall effect sensor H_1 as opposed

to Hall effect sensor H_2, Hall effect sensors H_1, H_2 provide substantially equal feedback that is directionally opposite, "$^{+}I_{B1}$" 21 and "$^{-}I_{B1}$" 24a respectively. That is, the feedbacks 21, 24a are substantially equal in magnitude but each has opposite polarity.

[Para 43] Following this convention, upon detecting another magnetic field B_2 17 that is induced or generated externally to the conductor 12a and generally impinges upon each Hall effect sensor H_1, H_2 substantially equally, the Hall effect sensors H_1, H_2 provide substantially equal feedback. Specifically, due to the directional configuration of the Hall effect sensors H_1, H_2, Hall effect sensors H_1, H_2 will both provide positive feedback 26, 28a, represented as "$^{+}I_{B2}$," upon detecting the magnetic field B_2. Even slight variations in the strength of the stray magnetic fields result in little error inducement because of the relative strength of the stray fields as compared to that of the sensed conductor.

[Para 44] All feedback, $^{+}I_{B1}$, $^{-}I_{B1}$, $^{+}I_{B2}$, and $^{+}I_{B2}$ is then passed to the processing component 18b. As previously described, according to the second configuration of the anti-differential current sensor 10b, the processing component 18b is configured in a differential configuration to generate the desired anti-differential output eliminating feedback generated upon detecting the externally induced magnetic field B_2. That is, the processing component receives the feedback $^{+}I_{B1}$, $^{-}I_{B1}$, $^{+}I_{B2}$, and $^{+}I_{B2}$ and algebraically calculates a summed difference. Specifically, a summed difference is generated as $(^{+}I_{B1} + {}^{+}I_{B2}) - (^{-}I_{B1} + {}^{+}I_{B2})$ yielding $^{+}2I_{B1}$, 30.

[Para 45] Therefore, through the second configuration of the anti-differential current sensor 10b includes a different configuration of the Hall effect sensors H_1, H_2 and the differential amplifier 18b rather than the summing amplifier 18a of Fig. 2, both the first configuration of the anti-differential current sensor 10a and the second configuration of the anti-

differential current sensor 10b yield the same anti-differential output 30 that effectively excludes influence from externally induced magnetic fields 17. As such, both the first configuration of the anti-differential current sensor 10a and the second configuration of the anti-differential current sensor 10b provide highly accurate current measurements by reducing, if not essentially removing, feedback associated with stray magnetic fields induced or generated externally to the conductor 12a from which current feedback is desired.

[Para 46] These highly accurate non-contact based current measurements of the above-described current sensor configurations allow the current sensor configuration to operate in environments having various external magnetic fields without degrading current measurements from a specific conductor. However, the accuracy of the current sensor in detecting a particular magnetic field associated with a particular conductor can be improved if the current sensor is configured, for example, for the particular conductor configuration and current level being monitored. Additionally, by disposing the sensors in close proximity to the monitored conductor or within current concentrating recesses, accuracy can be improved.

[Para 47] By matching the Hall effect sensors, the system is substantially free of errors due to zero flux offsets and Hall effect gain differences. Furthermore, matching the Hall effect sensors substantially corrects zero flux offset drift associated with temperature fluctuations. However, for configuration utilizing a single Hall effect sensor, it is contemplated that active electronic correction may be utilized to offset zero flux offset drift associated with temperature fluctuations.

[Para 48] Referring to Fig. 4, the strength of magnetic fields induced by current flow through a plurality of conductors and the strength of such at various distances are shown. Figure 4 shows that the magnetic field detected by current sensors associated with three different conductor sizes, at three

current levels, exponentially decreases as the distance from the center of the conductor increases. For example, the external magnetic field 32 detected by a current sensor disposed 0.4 inches from a 1/0 wire carrying 45 amps is substantially proportionate to the magnetic field 34 detected at only 0.1 inches from a No. 6 AWG wire carrying 13.3 amps. Accordingly, to overcome interference from a magnetic field induced by an adjacent 1/0 wire carrying 45 amps, a current sensor configured to monitor the No. 6 AWG wire carrying 13.3 amps should have a common mode field correction capacity of at least 16% of the rating of the No. 6 AWG wire.

[Para 49] This point is illustrated in Figs. 5 and 6, which show the magnetic flux interactions due to adjacent parallel conductors 36, 38 carrying approximately 100 amps of current in opposite directions. Figure 5 shows the interaction of magnetic fields induced by adjacent conductors 36, 38 in close proximity. Concentric circular shadings 40 represent the strength of the magnetic fields induced by the current flow through the conductors 36, 38. The magnetic fields induced by each conductor 36, 38 interact to form a combined oval magnetic field 40 rather than two independent magnetic fields. In this case, a current sensor disposed to monitor one of the conductors 36, 38 will detect a relatively large externally induced magnetic field. As such, the monitor must have a relatively high common mode field correction capacity forming a tolerance or “buffer” for the influence of magnetic fields induced externally from the conductor being monitored. While significantly high common mode field correction capacities are readily attainable, it is often desirable to limit the common mode field correction capacities so as to control costs. For example, the common mode field correction capacity of a sensor may be configured to be 25% of the conductor rating. In this case, a separation of adjacent conductors is desirable to assure that the common mode field correction capacity of the sensor is not exceeded.

[Para 50] Referring to Fig. 6, the adjacent, parallel conductors 36, 38 are separated so that the induced magnetic fields 42, 44 are sufficiently isolated

so as to remain below the common mode field correction capacity of a given sensor. Specifically, the conductor gage and corresponding amperage rating must be considered against the common mode field correction capacity of a sensor to determine the preferable separation of the conductors 36, 38. For example, should a sensor be configured to have a common mode field correction capacity of 25%, a separation of approximately three times the radius of the conductor 36, 38 would be a preferred minimum separation. Accordingly, a sufficient buffer is formed to tolerate the influence of magnetic fields induced externally from the conductor being monitored without affecting the summed difference calculated from the feedback generated by the sensor.

[Para 51] This principle can be extended to multiple adjacent conductors in various forms arranged in an array. That is, Figs. 5 and 6 illustrate wire conductors 36, 38 for exemplary purposes only. Other conductor forms such as bus bars and the like may be preferable in some configuration and are also contemplated. Specifically, when using wires in an array formation the separation requirements are compounded as additional conductors are added and/or wire gages increased. As such, it is often desirable to utilize bus bar configurations whereby conductor “radius” is reduced, thereby reducing adjacent conductor separation requirements.

[Para 52] The present invention yields error correcting for externally induced magnetic fields for current sensing and monitoring of both AC and DC power sources. The anti-differential output generated is high fidelity due to the absence of magnetic core materials. Low inductance, achieved as a function of an air core configuration, allows the current sensor configuration to be highly responsive to change as well as provides in-phase, real-time, current feedback vectors. The sensor configuration includes wide and dynamic range abilities due to the absence of permeable materials and the absence of a saturation point.

[Para 53] Additionally, the absence of non-linear saturating or ferromagnetic core materials eliminates DC error offsets associated with hysteresis of ferromagnetic materials and allows the current sensor configuration to be utilized to monitor AC and DC circuits. Therefore, the system generates an anti-differential output that is substantially free of variations due to hysteresis, magnetic core saturation, and eddy currents because the system is substantially free of ferromagnetic field concentrating materials. Furthermore, the elimination of metallic core materials reduces the overall size of the current sensor configuration and lowers consumed power. The sensor configuration is flexibly deployable to conductors including current flows from a few milli-amps to a few thousand amps.

[Para 54] By matching the Hall effect sensors, the system is substantially free of errors due to zero flux offsets and Hall effect gain differences. Furthermore, matching the Hall effect sensors substantially corrects any zero flux offset drift associated with temperature fluctuations. Furthermore, a constant current power supply may be utilized having a bias current compensation circuit or a temperature dependent adjustable gain to compensate for Hall gain drift. Additionally or alternatively, the processing component includes a temperature dependant op-amp gain loop configured to compensate for temperature dependent electronic drift. Also, Lorentz force drifts associated with temperature variations can be corrected using by the temperature dependent supply to power the anti-differential current sensor.

[Para 55] Additionally, while the above-described system is described with respect to utilizing a pair of Hall effect sensors within the anti-differential topology, it is contemplated that alternative magnetic flux sensors may be equivalently utilized. Specifically, magnetoresistive structures (MRS), giant magnetoresistive structures (GMRS), and the like may be equivalently utilized within the anti-differential topology.

[Para 56] While the above-described technique has been described with respect to current monitoring systems, it is equivalently applicable for voltage and/or power monitoring systems. That is, it is contemplated that additional systems and subsystems may be utilized with the above described techniques and topologies to equivalently generate highly accurate voltage and/or power measurements.

[Para 57] Therefore, the present invention includes a current monitoring system having a conductive path configured to receive a current therethrough, a first current sensor positioned on a first side of the conductive path and configured to monitor a first directional magnetic field induced by the current, and a second current sensor positioned on a second side of the conductive path, substantially opposite the first current sensor, and configured to monitor a second directional magnetic field induced by the current that is substantially opposite in direction to the first directional magnetic field. A processing component is configured to receive feedback from the first current sensor and the second current sensor and generate an anti-differential output from the feedback.

[Para 58] According to another embodiment of the invention, a current sensor includes a first Hall effect sensor positioned proximate to a conductor and configured to provide a first feedback indicative of a current flow through the conductor and a second Hall effect sensor positioned proximate to the conductor and configured to provide a second feedback indicative of the current flow through the conductor. A processing device is configured to generate a summed difference of the first feedback and the second feedback to reduce feedback corresponding to magnetic fields induced externally from the conductor.

[Para 59] Another embodiment of the present invention includes a method of determining current flow through an electrical path. The method includes

generating a first feedback represented by a first vector having a first direction and a first magnitude upon detecting a first direction of magnetic flux induced by a current flow through an electrical path and a second vector having the first direction and a second magnitude upon detecting a second direction of magnetic flux induced externally from the electrical path. The method also includes generating a second feedback represented by a third vector having the first direction and the first magnitude upon detecting a third direction of magnetic flux induced by the current flow through the electrical path and a fourth vector having a second direction and the second magnitude upon detecting the second direction of magnetic flux induced externally from the electrical path. The method then includes summing the first feedback and the second feedback to create an anti-differential sum thereby substantially canceling the effects of the first feedback and the second feedback represented by the second vector and the fourth vector.

[Para 60] A further embodiment of the present invention has an anti-differential current sensing system that includes an electrically conductive path. A first Hall effect sensor is disposed proximate to a first side of the electrically conductive path and configured to generate a first measure of a current flow through the electrically conductive path by monitoring magnetic fields and a second Hall effect sensor is disposed proximate to a second side of the electrically conductive path, substantially opposite the first side of the electrically conductive path, and configured to generate a second measure of the current flow through the electrically conductive path by monitoring magnetic fields. A processing device is configured to receive the first measure of the current flow and the second measure of the current flow and generate an output from the first measure of the current flow and the second measure of the current flow substantially free of errors due to magnetic fields generated externally from the conductive path.

[Para 61] According to another embodiment of the invention, a current sensor system includes means for carrying current and means for generating a first

feedback upon detecting magnetic flux in a first direction induced from the means for carrying current. The current sensor system also includes means for generating a second feedback upon detecting magnetic flux in a second direction induced from the means for carrying current, wherein the first direction is substantially opposite the direction and means for generating an anti-differential sum from the first feedback and the second feedback to reduce feedback generated upon detecting stray magnetic flux.

[Para 62] The present invention has been described in terms of the preferred embodiment, and it is recognized that equivalents, alternatives, and modifications, aside from those expressly stated, are possible and within the scope of the appending claims.